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5. FUNDING NUMBERS
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6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER

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U. S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

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11. SUPPLEMENTARY NOTES
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13. ABSTRACT (Maximum 200 words)

The high-speed infrared camera that has been acquired through the auspices of the DURIP grant provided by the ARO is a one-of-a-kind high performance equipment. We received the funding in February of 1999 and placed the purchase order for the camera in June 1999, with Leake Co. (Mfr: Pacific Advanced Technology), the same vendor that we said we would buy the camera from in our proposal. They originally quoted us a 3-month delivery time but ran into some technical difficulties due to the fact that they were migrating the Digital Control Electronics Module to a PC based next generation version. We actually received the camera only in February of 2001!

The research proposed included (i) characterization of the contact conditions at the chip-tool interface in machining, (ii) characterization of material behavior under high strain, strain rate and temperature, and (iii) development of simulations to fine-tune friction and constitutive models. We have made significant advances in objectives (i) and (iii) using funding available from local industries for related projects, as described in the report. We are currently in the process of acquiring funding to complete the rest of the research proposed.

14. SUBJECT TERMS
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Infrared Pyrometry

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WICHITA STATE UNIVERSITY

Department of Industrial and Manufacturing Engineering

May 16, 2001

U.S. Army Research Office
ATTN: AMSRL-RO-BI (TR)
P.O. Box 12211
Research Triangle Park, NC 27709-2211

Re: *Final report for the Army Research Office grant #DAAD19-99-1-0100*
"Instrumentation Request: High Speed Infrared Focal Plane Array Camera"

Dear Sir/Madam:

Please find enclosed the final report for the above grant. I am also enclosing copies of three papers detailing progress in achieving the objectives of the proposal that we had submitted.

It actually took the vendor 20 months to deliver the camera to us in February 2001, though they had originally quoted a three-month time-period for delivery. This caused the project to run beyond even the original extension that we had requested. I appreciate your patience in this regard.

Thank you very much.
Best Regards,

V. Madhavan

Vis Madhavan
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CONTRACT/GRANT NUMBER: DAAD19-99-1-0100

REPORT TITLE: Instrumentation Request: High Speed Infrared Focal Plane Array Camera

is forwarded for your information.

SUBMITTED FOR PUBLICATION TO (applicable only if report is manuscript):

Sincerely,

V. Madhavan

ASST. PROFESSOR, IMFGE
WICHITA STATE UNIVERSITY
WICHITA, KS 67260-0035

Instrumentation Request: High Speed Infrared Focal Plane Array Camera

Vis Madhavan
Dept. of Industrial and Manufacturing Engineering
Campus Box 35, Wichita State University
Wichita, KS 67260-0035

Original Budget

AMBER Engineering, Series 7000 AE187 FPA camera	105,000
PAT Photon series sensor head module	59,800
Digital control electronics module and software	17,000
25mm lens 3,000	
DIOP microscope with 1× and 4× objectives	13,500
Total Equipment Cost	**198,300**

Proposed Sources for Equipment

1. All items listed above, except the DIOP microscope will be purchased from
   Leake Company
   10920 Switzer Ave., Suite 101
   Dallas, TX 75238
   Ph.: 214-343-1266
   Fax: 214-343-3800
   Contact person: Mr. Jeff Leake.
2. The Diop microscope will be purchased from
   Diversified Optical Products
   282-T Main St.
   Salem, NH 03079-2796
   Ph.: 603-898-1880
   Fax: 603-898-8970
   Contact person: Mr. Lou Fantozzi, Jr.

List of Equipment Acquired

AE-187-1 FPA, Mfr: Raytheon Electronic Systems, Vendor: Leake Co.	94,900
LN2 Dewar with interchangeable cold filter, Vendor: Leake Co.	12,325
PAT Photon Series 6000 Custom FPA Drive Electronics consisting of Sensor Head Module Host PC-based control and data acquisition module Mfr: Pacific Advanced Technology, Vendor: Leake Co.	85,700
25mm lens, Mfr: Janoss Technology Inc.	1,995
Bayonet mount lens extenders, Mfr: Janoss Technology Inc.	623
Narrow band infrared filters, Mfr: DIOP Inc.	700
Split dual band infrared filters, Mfr: Barr Associates Inc.	2,160
Optical breadboard: Mfr. Newport Corp.	1,720
Angle brackets; Mfr: Oriel Instruments	350
Strip heater, relay and temperature controller for calibration; Mfr: Watlow	266
Heavy duty tripod, Mfr: Bogen, Vendor: Troxel Communications Inc.	535
Machining cost for calibration fixture	650
Total Equipment Cost	**201,924**

Description of Special Circumstances Regarding the Acquisition of the Instrument

The high-speed infrared camera that has been acquired through the auspices of the DURIP grant provided by the ARO is a one-of-a-kind high performance equipment, shown in Figure 1. We received the funding in February of 1999 and placed the purchase order for the camera in June 1999, with Leake Co. (Mfr: Pacific Advanced Technology), the same vendor that we said we would buy the camera from in our proposal. They originally quoted us a 3-month delivery time but ran into some technical difficulties due to the fact that they were migrating the Digital Control Electronics Module to a PC based next generation version. **We actually received the camera only in February of 2001!** Wary of such a possibility, before placing the order we considered whether to purchase the older generation of electronics, but the advantages offered in terms of reliability, image storage capacity and ease of use due to the addition of a few custom features prompted us to go with the newer version.

We have procured various accessories for the camera as listed above. The split dual band infrared filters are used as the cold filters so that real time dual wavelength temperature measurements can be carried out. Most of the other accessories are for securely holding the camera and for calibrating the non-uniformity of the pixels as a function of radiation intensity. Since the price of the newer version of electronics was marginally higher than that originally quoted to us, we have delayed acquisition of the infrared microscope lens and are currently investigating the feasibility of using the 25 mm lens with lens extenders instead.

Figure 1: High-speed infrared FPA camera

Summary of Research Projects Planned and in Progress

The research proposed included (i) characterization of the contact conditions at the chip-tool interface in machining, (ii) characterization of material behavior under high strain, strain rate and temperature, and (iii) development of simulations to fine-tune friction and constitutive models. We have made significant advances in objectives (i) and (iii) using funding available from local industries for related projects. We are currently in the process of acquiring funding to complete the rest of the research proposed.

In a collaborative effort with researchers at Purdue University, we have used a lower speed infrared camera for carrying out research into the contact interactions at the chip-tool interface in machining, at lower cutting speeds [1]. It is found that the temperature distribution is quite complex, due to the adhesion of the work material to the tool in certain regions. The average temperature as a function of the chip-tool contact length is however found to correlate well with the distribution predicted by moving heat source theory. We have also made progress in high-speed visible wavelength observations of the dynamic contact interactions during the machining of copper. For some contact pairs, such as copper and sapphire, a stick-slip mode of contact is observed at high cutting speeds. These results have been published as an AIAA conference paper [2] and are being readied for possible publication in the Journal of Tribology.

We have recently obtained funding from local industries, Boeing Co., Cessna Aircraft Co. and Raytheon Aircraft Co., to expand on this effort and obtain the chip-tool interface temperature distribution while machining aluminum and titanium alloys of interest to these industries. The chip-tool interface temperature can be used to estimate tool life and to check the validity of commercially available machining packages that are currently being used in industry. Knowledge of the temperature distribution will allow back-calculation of the friction at the chip-tool interface, which can be used for evaluating different tool coatings and as input for finite element analysis of machining. This will help our industrial partners improve tool life and productivity in machining of hard to machine materials such as Titanium. The high-speed infrared camera acquired through this DURIP grant is central to this research.

We have developed capabilities for theoretical and computational analysis of 2D and 3D machining operations that can be used to fine-tune and validate constitutive and friction models. Theoretical analysis capabilities include an implementation of Oxley's model for orthogonal machining, its extension to use the Johnson-Cook material model and an upper bound analysis of generalized 3D machining with nose radius tools. We can carry out finite element analysis of orthogonal machining, turning and milling using Lagrangian, Eulerian and ALE capabilities available in software such as LS-DYNA, MARC and ABAQUS. Some of these developments have been presented as a keynote address at the *Forum on CFD in Manufacturing Processes* in the 1999 ASME IMECE [3].

References

1. Narayanan, V., Krishnamurthy, K., Madhavan, V., Chandrasekar, S. and Farris, T.N., "Measurement of the Temperature Field at the Tool-Chip Interface in Machining", accepted for publication in the *Proceedings of the Symposium on Fundamental Issues in Machining*, ASME IMECE 2001.
2. Harikeshavan, G. and Madhavan, V., "Evaluation of chip-tool interface conditions through transparent tools", SAE GCRAM 99, April 20-22, Wichita, Kansas. SAE paper #1999-01-1563.
3. Madhavan, V., Olovsson, L., Swargam, S.C., and Agarwal, R., "Eulerian finite element analysis of 3D machining", Invited keynote presentation, *Forum on CFD in Manufacturing Processes*, ASME IMECE '99, Nashville, TN. November 14-19, 1999. FED-Vol. 250, pp. 149-155.